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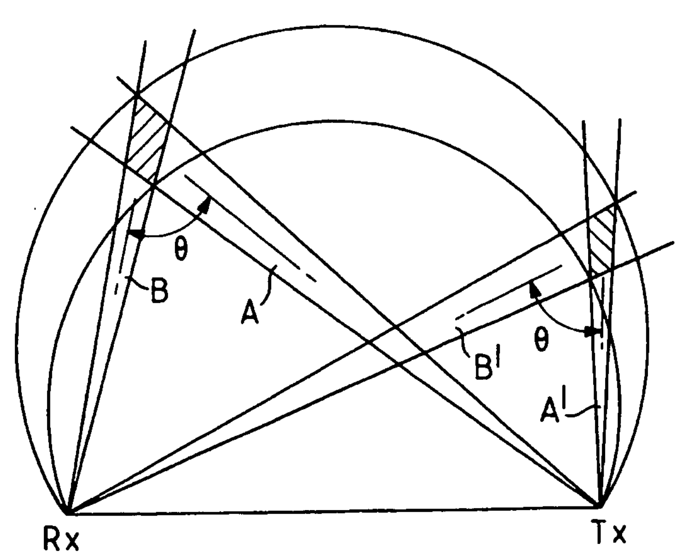
(54) **Bistatic radar**

(57) A radar comprises a transmitting station T_x and a spaced receiving station R_x, each station having a steerable antenna capable of tracking through a limited angle in azimuth. The antennae are controlled such that on one half of a sweep the beams (A and B) sweep a volume of space, whilst on the other half of the sweep the beams (A' and B') sweep a different volume of space at a different range from the receiver (R_x).

Fig. 1.



The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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Fig. 1.

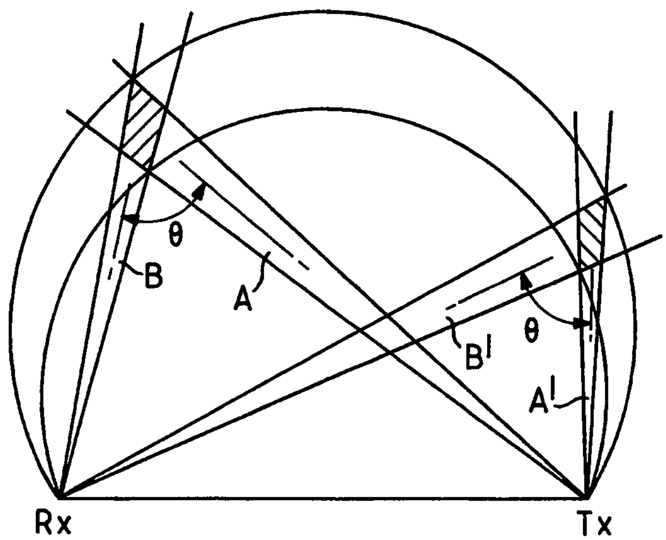


Fig. 2.

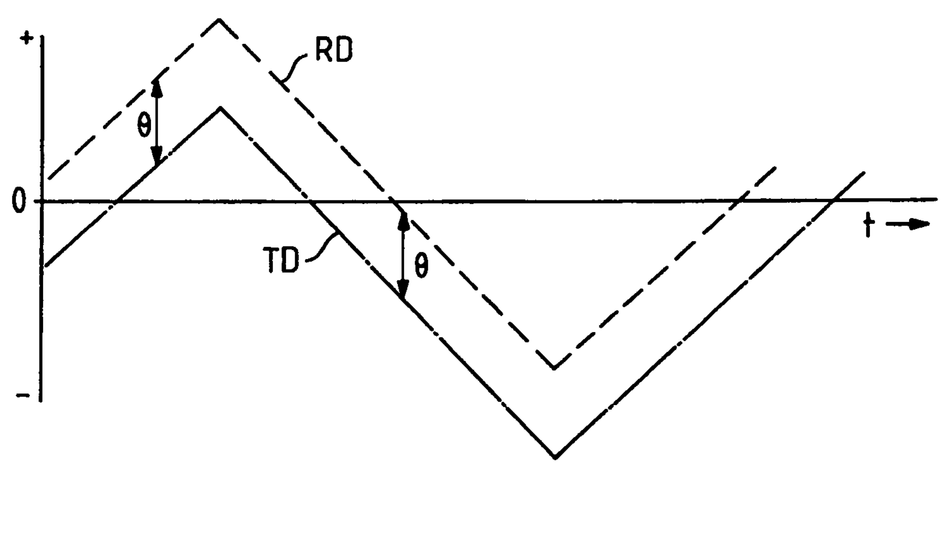


Fig. 3.

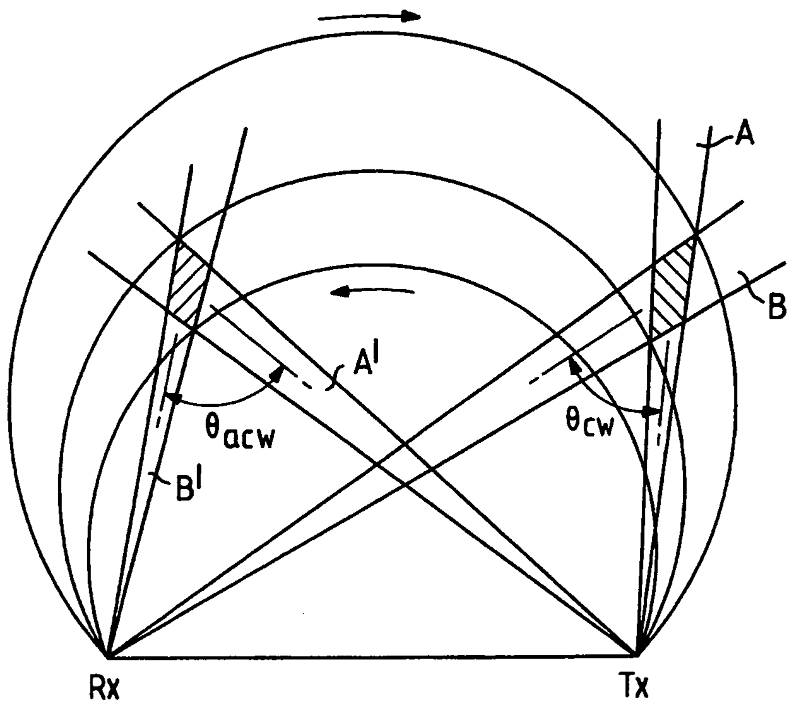

A
B
A'
θ_{acw}
θ_{cw}
B'
Rx
Tx

Fig. 4.

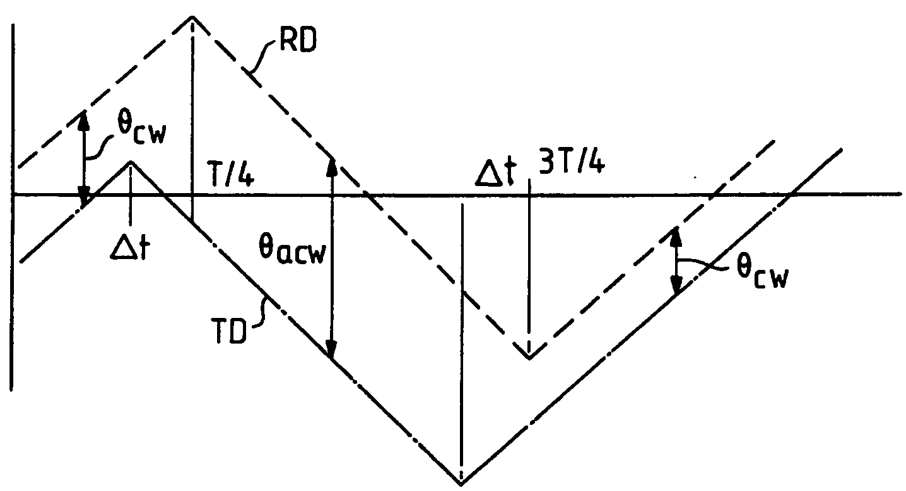
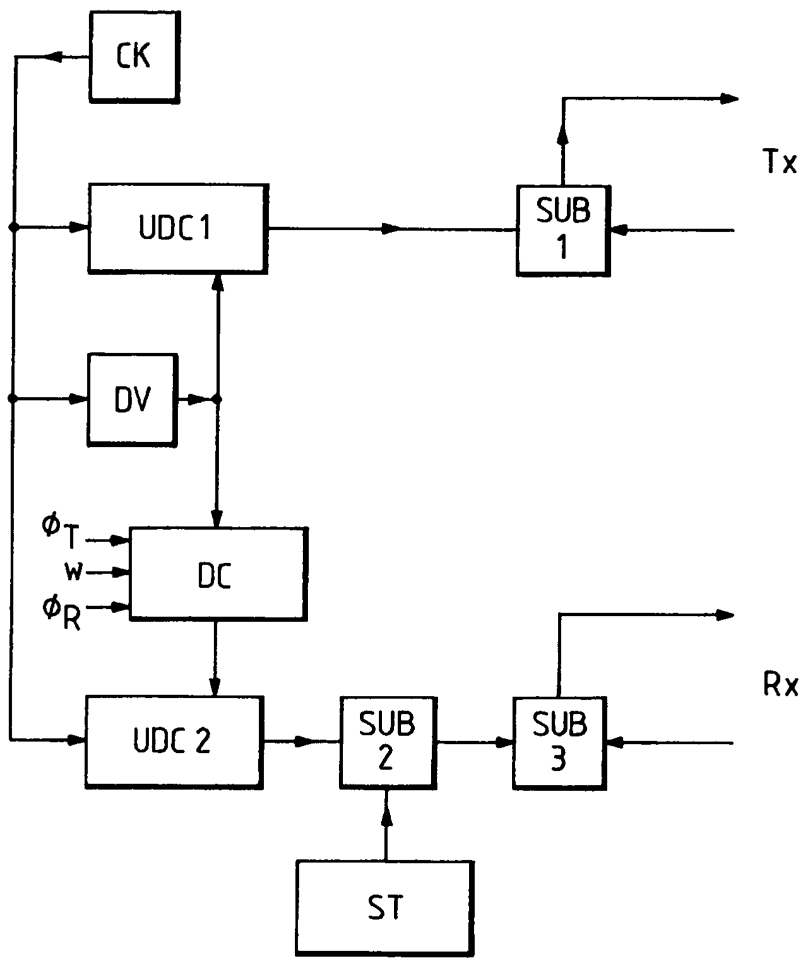

RD
θ_{cw}
T/4
Δt
3T/4
Δt
θ_{acw}
TD
θ_{cw}

Fig.5.



SPECIFICATION

Radar systems

Radar systems are in common use for the detection and tracking of airborne targets such as aircraft and missiles. Although many systems share an antenna between a transmitter and a receiver, it is known to separate the transmit and receiver antennae. This enables triangulation techniques to be used for the location of the target. An additional advantage is that the separation reduces the problem of "clutter", that is strong unwanted return signals due to objects which are close to both the transmitter and receiver.

When the antennae are well separated, providing what is known as a "bistatic" system, the scans of the two antennae have to be synchronised, so that a known volume of space is scanned. This volume is that over which the beam from the transmitting antenna intersects the beam of the receiver antenna. Hence the range at which surveillance cover is obtained is controlled by the angle of the beams of the transmitter and receiver antennae, and the angle at which the beams converge. Thus the range may be varied by varying the convergence angle. Many bistatic systems operate over limited scan angles; for example a coastal radar system is frequently not required to scan on the landward side of the base line joining the transmitter and the receiver. In such a case, a scan cycle is made up of two half-cycles scanned in opposite directions, usually at constant velocity. This may be used to increase the apparent scan rate without increasing the speed of rotation of the antennae, since each half cycle of the scan may cover the same volume of space.

It is an object of the invention to increase the volume of space covered during a single scan cycle of the antennae.

According to the present invention there is provided a radar system comprising a transmitting station and a receiving station located at separate spaced locations, an antenna system at each location capable of tracking through a limited angle in azimuth such that a complete scan cycle comprises two half-cycles scanned in opposite directions, and antenna control means operable to control the orientation of the two antennae such that the two half cycles of a scan cover volumes of space at different ranges from the receiving antenna.

An embodiment of the invention will now be described with reference to the accompanying drawings, in which:-

Figure 1 illustrates the arrangement and operation of a known bistatic radar system;
Figure 2 is a diagram illustrating the antenna drive signals for the system of Figure 1;
Figure 3 illustrates the operation of a radar system according to the invention;
Figure 4 illustrates the antenna drive signals for the system of Figure 3; and
Figure 5 shows a block diagram of circuitry for implementing the invention.

Referring now to Figure 1, a radar system of the type referred to, namely a bistatic system, has a transmitter Tx and a receiver Rx separated along a base line. The transmitter and receiver each have a steerable antenna movable through a limited angle of azimuth and elevation. Each antenna has a narrow beamwidth. By way of example only, the range of azimuth angle may be of the order of 75°, with an antenna beamwidth of 0.5°.

Figure 1 also illustrates how a bistatic system operates. The transmitter Tx emits radiation continuously or in pulses, and hence illuminates a volume of space defined by the width of the transmitter beam A. If the receiver antenna is pointing in a suitable direction, then the receiver antenna will detect radiation reflected from an object in an appropriate part of the transmitter beam A. The volume of space covered by the receiver antenna beam is denoted at B. Hence any object in the volume over which beams A and B intersect will be detected by radiation reflected to the receiver antenna. Similarly, the Figure shows at A' and B' the situation when the transmit antenna has rotated in azimuth in a clockwise direction through a certain angle, and the receiver antenna has rotated in the same direction through the same angle. The conveyence angle θ between the two beams is shown. In a conventional bistatic system the antennae scan backwards and forwards in step with one another, covering the same surveillance volume on each half-cycle of the scan. If the transmitter and receiver antennae rotate at a constant rate, then the volume of space or surveillance volume over which the beams intersect is crescent-shaped, as shown in Figure 1, being bounded by two circles which pass through transmitter and receiver.

The range of the surveillance volume from the receiver varies throughout each half-cycle of the scan, but is readily determined. It depends upon the angular relationship of the two antennae at the start of each scan. The general position of the scanned volume is therefore determined by the requirements of the radar system.

Figure 2 shows the form of the antenna drive signals for the transmit and receive antennae. Each signal is a reversing ramp function. Two curves are shown, one, RD, for the receive antenna, and the other, TD, for the transmit antenna. The curves indicate, at any instant in time, the bearing of the appropriate antenna, and the convergence angle θ is given by the vertical distance between the two curves. Since the area scanned as shown in Figure 1 is the same for both clockwise and anticlockwise rotation of the antennae, the two in Figure 2 are always the same vertical distance apart.

It would be useful if a radar system could cover a large surveillance volume in a scan cycle, but to enlarge the volume usually means increasing the antenna beamwidth. However this results in a loss of radar power and definition. It is possible to increase the beamwidth of the receiver antenna alone, and this is frequently

done by providing a number of feed horns each supplying signals to a separate receiver.

Figure 3 illustrates a way of increasing the surveillancce volume even further. In this example, beams A and B trace out a crescent-shaped volume as before over half a cycle of the scan, say during the clockwise rotation of the antennae. At the end of the half-cycle, the convergence angle between the two antennae beams is changed from θ_{cw} to θ_{acw}. This has the effect of moving the position of the volume at the intersection of the beams. Thus the two antennae cover a second crescent-shaped volume at a greater range than the first. At the end of the second half-cycle of the scan, the convergence angle between the two beams is restored to its original value, so that the first area is again covered. The two volumes shown in Figure 3 are contiguous. However, by suitable variation of the convergence angle the two volumes may be separated, or may overlap. In order to produce contiguous zones, the convergence angle during one half of the sweep must be different from that during the other half of the sweep by an amount equal to the sum of the beamwidths of the two antenae.

Figure 4 shows the two antenna drive signals necessary to produce the desired effect. The convergence angle during the clockwise part of the scan is shown as θ_{cw}. As shown in Figure 4, the scan of the transmit antenna is reversed before that of the receive antenna, the time interval between the two reversals being shown as Δt. As a result, the convergence angle during the anticlockwise part of the scan is increased to a value θ_{acw}. At the end of this second part of the scan the transmit antenna is again reversed a time Δt before the receive antenna, restoring the convergence angle to $\theta c\omega$.

The time interval Δt may be defined by the expression.

$$\Delta t = 1/2\omega.(\phi_T - \phi_R)$$

where

ω is the constant angular scan rate of each antenna,

ϕ_T is the beam width of the transmit antenna, and

ϕ_R is the beam width of the receive antenna.

The relationship between the two convergence angles may be expressed as

$$\theta_{acw} = \theta_{cw} + \phi_T + \phi_R.$$

If overlapping or separated swept volumes are required on the clockwise and anticlockwise parts of the scan, then the above expressions will not apply.

Whether control is excercised in an analogue or a digital manner, the bearings of the two antenna from a datum position may be denoted by suitable equations. The equations given below for receiver antenna bearing θ_R and transmitter antenna bearing θ_T apply when contiguous volumes are being scanned. For each antenna the cycle may be split into three sections.

Thus:-

$$\theta_R = \theta_{Ro} + \omega t \qquad \text{for } 0<t<T/4$$

and $$\theta_R = \theta_{Ro} + \omega T/2 - \omega t \qquad \text{for } T/4<t<3T/4$$

and $$\theta_R = \theta_{Ro} - \omega T + \omega t \qquad \text{for } 3T/4<t<T$$

where

θ_{Ro} is the receive antenna bearing when $t = 0$

T is the scan cycle period

and ω is the constant angular scan rate.

and:-

$$\theta_T = \theta_{Ro} - \theta_{cw} + \omega t \qquad \text{for } 0<t<(T/4 - \Delta t)$$

and $$\theta_T = \theta_{Ro} - \theta_{cw} + \omega(T/2 - 2\Delta t) - \omega t \qquad \text{for } (T/4 - \Delta t)<t<(3T/4 - \Delta t)$$

and $$\theta_T = \theta_{Ro} - \theta_{cw} - \omega T + \omega t \qquad \text{for } (3T/4 - \Delta t)<t<T$$

where

θ_{cw} is the beam convergence angle during, say, clockwise scan,

and $\Delta t = 1/2\omega(\phi_T + \phi_R)$

The necessary control to apply these equations may be effected in a number of ways. Antenna control systems usually employ digital techniques, in which case the necessary ramp functions are in fact produced by a large number of small steps. Hence one way of providing the necessary control is to provide a processor which will continually solve the equations given above. If the radar system to which the invention is applied is already controlled by a processor, then it is only necessary to modify the program accordingly.

Alternatively a logic circuit may be derived to provide the necessary control, and Figure 5 is a block diagram of such a logic arrangement.

Referring now to Figure 5, this shows a clock pulse generator CK applying clock pulses to an incremental reversible counter UDC1. The clock pulses are also divided down in a divider DV to produce synchronising pulses for the counter at a rate determined by the scan period of the system. The synchronising signals determine the instant at which the direction of count of the reversible counter occurs. The counter produces a ramp output which is reversed by the synchronising pulses from the divider, so that a triangular waveform is produced. This forms the antenna azimuth demand for the transmit antenna. A subtractor SUB1 subtracts from this demand the actual antenna azimuth position obtained from a suitable transducer, and derives the error signal output to be applied to the antenna azimuth servo. It will be seen that the transmit antenna demand will be of the form described with reference to Figure 4.

A second incremental reversible counter UDC2 is also supplied with clock pulses, and derives a second triangular waveform. However, the reversals of this counter is delayed by passing the synchronising output of divider DV through a delay circuit DC, which provides a delay equal to the value Δt discussed above. In order to derive the value Δt the delay circuit DC has inputs denoting the values of ω, ϕ_T and ϕ_R, all of which will be constants.

The output from the second counter UDC2 is a second triangular waveform the reversals of which are delayed with respect to that from counter UDC1 by the time Δt. However, it is necessary to provide an azimuth offset between the two triangular waveforms in order to produce the desired relationship between the clockwise and anticlockwise convergence angles. This offset is provided by subtracting in subtractor SUB2 a constant value equal to $\theta_{cw} + 1/2\ (\phi_T + \phi_R)$, and determines the average range of both sections of the scan pattern. The output of subtractor SUB2 then forms the demand input to the receive antenna azimuth drive. Subtractor SUB3 subtracts from this demand the actual receive antenna azimuth position obtained from a transducer, and derives the error signal output to be applied to the antenna azimuth servo. The receive antenna servo demand will be of the form described with reference to Figure 4.

Other logic arrangements may be used to produce the desired effect. As already stated, the embodiment described with reference to Figures 3, 4 and 5 relates to an antenna sweep pattern covering two contiguous areas.

CLAIMS

1. A radar system comprising a transmitting station and a receiving station located at separate spaced locations, an antenna system at each location capable of tracking through a limited angle in azimuth such that a complete scan cycle comprises two half-cycles scanned in opposite directions, and antenna control means operable to control the orientation of the two antenna such that the two half cycles of a scan cover volumes of space at different ranges from the receiving antenna.
2. A system as claimed in Claim 1 in which the antenna control means are operable to change the convergence angle between the beams of the two antenna systems between successive half-cycles of the sweep.
3. A system as claimed in Claim 2 in which the antenna control systems includes means for generating for such antenna systems an azimuth demand signal of substantially triangular waveform, and means for delaying the successive reversal points of one waveform relative to the other by a predetermined time interval.
4. A system as claimed in Claim 3 in which the two volumes of space swept in the two half-cycles of a scan are contiguous the predetermined time interval being half the time taken for either antenna to scan through an angle equal to the difference between the two convergence angles necessary to sweep the two volumes.
5. A system as claimed in Claim 4 in which the antenna control system includes means for applying an azimuth angle offset to said one waveform, the value of the offset determining the average range of the swept volume from the receiver.
6. A radar system substantially as herein described with reference to the accompanying drawings.

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